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Impact of human mobility on wireless ad hoc networking in entertainment parks

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ABSTRACT

Ad hoc networks of wireless devices carried by entertainment park visitors can support a variety of services. In such networks, communication links between the devices sporadically appear and disappear with the mobility of visitors. The network performance strongly depends on how often they encounter each other and for how long the contact opportunities last. In this paper, we study the mobility of visitors based on GPS traces collected in two entertainment parks. We demonstrate and discuss the implications of the observed mobility on the efficiency of opportunistic data forwarding. We show how hourly changes in the number and spatial distribution of the park visitors affect the delay of a broadcast application. Our results suggest that generic mobility models commonly used in wireless research are not appropriate to study this and similar scenarios: Targeted mobility models are needed in order to realistically capture non-stationarity of the number and spatial distribution of nodes. Therefore, we developed a mobility simulator for entertainment parks that can be used to scale up the evaluation scenarios to a large number of devices. The simulator implements an activity-based mobility model, where the mobility of park visitors is driven by the activities they wish to perform in the park. The simulator is calibrated based on the GPS traces and validated on several metrics that are relevant for the performance of wireless ad hoc networks.

1. Introduction

For many wireless services, a continuous connectivity and end-to-end paths are not necessary. Unlike in infrastructure-based networks that provide full wireless coverage, in the so-called ad hoc networks wireless devices communicate directly when within each other's range. This communication mode is useful when infrastructure-based communication is costly or unavailable. When devices are mobile (e.g. carried by people), the ad hoc communication may experience occasional disruptions as links between devices appear and disappear with changes in the distance between the devices. Network applications and protocols need to be delay and disruption tolerant to benefit from such intermittent connectivity [1,2]. This requires re-design of many protocols, especially routing protocols, since an end-to-end path between devices is not necessarily available throughout a communication session [3]. Therefore, messages are forwarded incrementally through the network in a store-carry-forward manner when contact opportunities arise. Understanding the mobility of people is crucial because mobility determines the rate and the duration of contact opportunities. Human mobility, however, is not easy to characterize. For example, working-day, shopping, and campus mobility will all result in different encounter patterns. For many practical applications, routing/forwarding algorithms must target specific mobility scenarios, even if this limits the scope of their applicability.

Future services offered to entertainment park visitors might rely on wireless technologies, devices, and applications [20]. Personalized location-based services, mobile

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trans-reality games, park information services, social networking, and multimedia sharing would make a visit to a park more interactive and entertaining. However, it cannot be assumed that wireless data service is available throughout the park. Cellular 3G coverage is typically available, but many park visitors are foreign tourists who do not have data plans with local operators and are not willing to pay data rooming charges. Rolling out extensive Wi–Fi infrastructure to support wireless services in an entertainment park is not an easy task: The largest parks are comparable in size with big cities (e.g. the Walt Disney World Resort in Florida spans over $\sim$100 km^2, an area as large as San Francisco). Although Wi–Fi infrastructure and wireless services would provide some added value to the visitors, it is often not clear how would they increase the revenue (e.g. attendance) of theme parks. Besides, since theme parks usually offer very unique experiences, there is no push from competition to provide such services. Due to the lack of strong reasons that would justify costly and logistically complex full-scale infrastructure deployment, alternative solutions that enable gradual introduction and testing of wireless services at low-cost are preferred. Such lightweight solutions would help park management assess the needs and tech requirements for possible future deployments. For some theme park applications continuous connectivity provided by fixed wireless infrastructures is not needed: Spotty coverage might be tolerated if supported by opportunistic store-carry-forward type of communication among visitors. Examples include distribution of park information (waiting times at different attractions, schedules of street parades and other performances), mobile advertising, collaborative localization, participatory sensing, polling/surveying, and multimedia sharing. Some of the application scenarios are described in Section 2. The applications may run on smart phones brought by visitors, or on customized devices handed out to the visitors. The latter could be optimized for opportunistic communication and park-specific scenarios.

In this paper, we study the mobility of park visitors based on GPS traces collected in two entertainment parks in order to understand network requirements for opportunistic communication (minimum number and density of mobile devices and supporting infrastructure nodes). On an example of epidemic broadcasting, we analyze the impact of hourly changes in visitors' mobility and density on the speed of content dissemination [41]. Contact-related statistics, such as inter-any-contact time and mean square displacement, are extracted from the traces and their impact on the broadcasting performance is discussed. The number of traces in our dataset, even though larger than in most datasets used in related studies, is not sufficient for large-scale evaluation. Therefore, mobility models that can produce realistic node encounter patterns are needed. Simplistic and rather generic mobility models, which are often used in wireless research, assume constant number and a stationary, steady-state spatial distribution of nodes in an area. Targeted mobility models are needed in order to realistically capture non-stationarity of the number and spatial distribution of nodes. We present an activity-driven mobility model of park visitors, which we implemented in our ParkSim simulator [42]. The model is calibrated based on the GPS traces and other data obtained from the entertainment parks. The outputs of the simulator are synthetic mobility traces of park visitors, which can be used for trace-driven simulations of mobile ad hoc networks.

The remainder of this paper is organized as follows: Some examples of the entertainment park applications that may benefit from opportunistic communication are given in Section 2. GPS traces are described in Section 3. The performance of opportunistic broadcasting is studied in Section 4. Contact-related statistics are analyzed in Section 5. A mobility model derived based on the GPS traces is described in Section 6. Section 7 concludes the paper.

2. Application scenarios

Some of the application scenarios for opportunistic networking in entertainment parks are described in the following.

2.1. Mobile trans-reality games

Mobile trans-reality games often rely on wireless technologies. Some of them can be supported with a gossip-based communication among players. A simple example is Insectopia [4], a game where players with mobile phones roam Bluetooth-rich environments searching for and catching a multitude of different "insects". Insect types are represented by unique Bluetooth signatures of the devices. In scavenger hunt games, team members often exchange information needed to complete their mission. Kim Possible [5] is a Disney game played in the Epcot park where players take roles of secret agents equipped with communication devices. Some games however do not revolve around technology and dedicated communication devices (i.e. mobile phones). In those games, gossip-based protocols can be used in real-world to mimic the way game characters (e.g. toys) would communicate with each other in a fantasy-world. For example, in a game designed for young children, a task could be to guide a toy character through missions during which the radio-enabled toy is empowered (e.g. with skills and knowledge) through contacts with other toys and objects in the park.

2.2. Mobile advertising

Mobile advertising can be used in entertainment parks to inform visitors about special events (e.g. shows, street performances and fireworks) and shopping/dining opportunities. Advertisements may take the form of electronic tips and discount coupons that are distributed wirelessly from infrastructure nodes and forwarded epidemically from a device to a device. The advertisements may target the entire park population (flooding), or a sub-population based on visitor's personal profile (multicasting) or current location (geocasting). Long waiting times at popular rides, which are common during summer vacations and holiday weekends, are undesirable. Opportunistic communication can be used to inform visitors about waiting times at different rides so that they can organize their visit time in a